COAL COMBUSTION PRODUCTS

By Rustu S. Kalyoncu

Coal combustion products (CCP's) are the resultant solid residues generated by coal-burning electric utilities in the production of electricity. Electricity accounts for about 35% of the primary energy use in the United States and is produced by electric power generators designed to convert different fuel types into electricity. Over one-half of the electricity in the United States is generated by burning coal. As a result, more than 100 million metric tons per year of CCP's are generated by the electric utilities. The coal is crushed, pulverized, and blown into a combustion chamber, where it immediately ignites and burns to heat boiler tubes. The inorganic impurities, known as coal ash, either remain in the combustion chamber or are carried away by the flue gas stream. Coarse particles (bottom ash and boiler slags) settle at the bottom of the combustion chamber, and the fine portion (fly ash) remains suspended in the flue gas stream. Unless precautions are taken, fly ash is released into the atmosphere with the flue gases. Prior to leaving the stack, however, fly ash is removed from the flue gas by electrostatic precipitators or other scrubbing systems, such as a mechanical dust collector, often referred to as a "cyclone." In addition to the above products, electric generators equipped with flue gas desulfurization (FGD) units generate what is known as FGD product.

The majority of electric power utilities, especially in the Eastern and the Midwestern States, use high-sulfur bituminous coal. Increased use of high-sulfur coal has contributed to an acid rain problem in North America. To address this problem effectively, the U.S. Congress passed the Clean Air Act Amendments of l990 (CAAA'90; Public Law 101-549) with stringent restrictions on sulfur oxide emissions.

The sulfur dioxide (SO_2) reduction provisions of CAAA'90, with a two-phase implementation plan, require the electric utilities to find ways of reducing SO_2 emissions. Many utilities have switched to low-sulfur coal or fuel oil as partial and/or temporary solutions to the problem. A significant number of those powerplants still using high-sulfur coal installed flue gas desulfurization (FGD) equipment.

FGD units help solve the SO_2 problem but, in doing so, add a side effect in the form of large quantities of a coproduct called FGD material, or FGD sludge. These coproducts of the FGD process, produced in inordinate quantities, add to the accumulation of already high levels of CCP's. Of approximately 23 million metric tons of FGD material produced as an FGD process byproduct in l997, approximately 9% percent was used, most of which was in agriculture and wallboard manufacturing. This figure, though modest, represents a twofold increase from that of 1993.

Among the industries directly or indirectly affected by FGD issues are coal, limestone, lime, soda ash, and gypsum producers. Increased commercial use of FGD products represents an economic opportunity for high-sulfur coal producers and the sorbent industry (especially lime and limestone).

Fly ash represents a major component (57%) of CCP's produced, followed by FGD material (24%), bottom ash (16%), and boiler slag (3%). More than 90% of the boiler slag is profitably used. Among the major CCP components, fly ash has represented the highest use rate at approximately 32% of the amount produced.

FGD Technology

Passage of the CAAA'90 by the 101st Congress and subsequent FGD requirements for coal-fired powerplants generated much activity in the research and development of processes to control SO_2 emissions in flue gas. Almost 200 FGD processes and 24 subsystems of processes have been identified (Radian Corporation, 1983). A significant number of electric powerplants, which continue to use medium- and high-sulfur coal as fuel, have installed FGD equipment. These systems are categorized into two major types, wet and dry systems, which, in turn have been assigned to 16 subcategories, but only a few have been developed to technically and economically feasible levels and even fewer to commercial scale. Among these, the lime/limestone process is the most widely used in the United States.

Approximately 90% of FGD systems installed in the United States use limestone or lime as a sorbent. Currently, over 10,000 megawatts of power generation systems support FGD units. More than 6,000 megawatts of limestone units and nearly 4,000 megawatts of lime units are being constructed. Moreover, 7,000 megawatts of limestone systems and 6,000 megawatts of lime systems are in the planning stage. When operational, these system are expected to triple the quantity of FGD products to about 75 million tons per year, from the current level of 23 million tons per year. Increased use of lime as a sorbent, however, can significantly lower the FGD product generation because lime is more reactive than limestone; consequently, higher efficiencies can be obtained with lime as the sorbent, and thus lesser amounts are needed.

In FGD systems using the quicklime (CaO) process, quicklime is slaked on-site to form a calcium hydroxide slurry. This slurry reacts with sulfur gases to form calcium sulfite and calcium sulfate. Sulfites formed need to be converted to sulfate which is done by increasing the oxygen content in the system, thus effecting the oxidation of sulfite to sulfate. The oxidation of sulfite to sulfate is dependent upon many process variables, such as equipment design, pH, and O_2 to SO_2 ratio. Sulfite formation causes serious operating problems due to scale formation in some systems.

Production

Table 1 lists the five-year historical data on CCP production for calendar years 1993 through 1997 collected by the American Coal Ash Association (ACAA) in surveys. The expected rise in the FGD material did not take place after the passage of the CAAA '90. Although only 10% of the utilities was affected by the first-phase implementation of the law, it was still expected to make a noticeable difference in the quantities of CCP produced. This did not take place primarily because in order to avoid high initial capital expenditures for FGD installations, many utilities, opted for temporary alternatives, such as fuel switching, power reduction, and purchase of emissions allowances. This trend has continued to date. As the implementation of the second phase of the law began, however, these first-phase options, especially emissions allowances, have become more expensive. This will compel the utilities to find a permanent solution to the emission problems, most likely through the installation of FGD units. In the coming years, the number of FGD units will probably increase; consequently, a commensurate rise in the FGD product will substantially add to total CCP's produced. The production data for CCP's are summarized on regional basis and various use categories in figures 1 through 7. Figures 1 and 2 shows the historical CCP production and use data for the last 5 years, and figure 3 shows the comparative production figures for 1997. Figures 4 and 5 show separate production data by geographic region and by CCP type. (See figure 12 for the States in each geographic region.) Figures 6 and 7 show the share of each CCP, by production and use, for 1997.

Consumption

Components of CCP's have different uses as they show distinct chemical and physical properties, thus making each one suitable for a particular application. CCP's are used in cement, concrete, mine backfill, agriculture, blasting grit, and roofing applications. Other current uses include, to a lesser extent, waste stabilization, road base/subbase, and wallboard production (FGD gypsum). The use of FGD gypsum in wallboard production has significantly increased. Potential FGD gypsum uses also include applications in subsidence control and acid mine drainage control and as fillers and extenders.

Total CCP's use increased to 26.5 million tons in 1997, an increase of almost 16% from that of 1996; changed little from 1994 to 1996. The greatest increase was recorded by the FGD material, which jumped to an all-time high of 32% from that of 1996. Storage type and various use categories for CCP's are listed in table 2. The use of the FGD gypsum in wallboard manufacture recorded the largest growth among the CCP's, increasing from 790,000 tons in 1996 to 1.46 million tons in 1997, an 85% increase. Among the application areas, agriculture (a 350% increase), mining applications (99%), road base/subbase (72%), structural fills (48%), and waste stabilization (49%) recorded the significant gains. Dry CCP's accounted for the increases in use categories, and ponded (wet) CCP's recorded a net decrease in use. (*See tables 3 and 4.*)

The use data for CCP's are summarized on regional basis and various use categories in figures 1 through 7. Figures 1 and 2 show the historical CCP's production and use data, respectively, for the last 5 years, and figure 3 shows the comparative use figures for 1997. Figures 4 and 5 present separate use data by geographic regions and by CCP type. As shown in figures 4 and 5, only a small fraction of total CCP's is used despite significant gains in recent years; almost 100% of boiler slags, however, is used (Barry Stewart, American Coal Ash Association, oral commun., 1998). Figures 6 and 7 show the share of each CCP by production and use, respectively, for 1997.

Figures 8 through 11 show the leading application for the four CCP's, namely fly ash, bottom ash, FGD product, and boiler slags. Among the CCP's, fly ash is used in the largest quantities and finds the widest applications, with about 60% of the annual production consumed in various structural applications. Use in cement and concrete production tops the list of leading fly ash applications with more than 50%, followed by structural fills and waste stabilization. *(See figure 8.)* Approximately one-half of bottom ash applications is for use in road base/subbase, cement and concrete, structural fill, waste stabilization, and snow and ice control. *(See figure 9.)* Miscellaneous other applications, such as mineral fillers and extenders, and flowable fill, make up the other one-half of the use categories. Mining applications (about one-half of the total used), agriculture (about one-third), and blasting/roofing granules account for the bulk of FGD product uses, amounting to more than 90% of its total use. *(See figure 10.)* Virtually 100% of the boiler slags produced are used. *(See figure 11.)* Owing to its considerable abrasive properties, boiler slag is almost exclusively used in the manufacture of blasting grit. Use as roofing granules is also a significant market area.

US Gypsum plans to use 100% FGD gypsum in its new 700-million-square-foot-per-year plant in Bridgeport, AL, which is scheduled to begin production in 1999. The company signed a long-term agreement with Louisville Gas and Electric Co. (LG&E) to receive more than 500,000 tons per year FGD gypsum from four power-generating units at LG&E's Mill Creek Station in Louisville, KY (Drake, 1997). LG&E is modifying its FGD units to produce wallboard-grade gypsum. Standard Gypsum is building a wallboard plant near Clarksville, TN, which will use 100% FGD gypsum supplied by the Tennessee Valley Authority's (TVA) Cumberland generating station, and is expected to begin operations in 1999 (Drake, 1997). The TVA is making the necessary technical modification to its Cumberland FGD unit to enable it to produce wallboard-quality gypsum for the new plant.

Georgia Pacific and National Gypsum are also in the process of building wallboard plants in Wheatfield, IL (Georgia Pacific), as well as in Shippingsport, PA, and St. Louis, MO (National Gypsum), which will use 100% FGD gypsum shown in figures 4 and 5, only a small portion of total CCP's is used despite significant gains in recent years; almost 100% of boiler slag, however, is used (Barry Stewart, American Coal Ash Association, oral commun., 1998).

Current Research and Technology

Research and development activities (R&D) have focused on improving FGD processes and finding new applications for CCP's, especially the FGD product. Much of the activity in new FGD technologies area has been spearheaded by Japanese and

West European researchers. Higher R&D activity levels in these countries is are driven by space limitations—the utility industries in these countries have no room for the disposal of the coproducts from the current FGD processes. The countries are, therefore, forced to find better solutions to flue gas emission problems. Research efforts emphasize the development of technology that requires less space for installation and yields smaller quantities of coproducts than the well-established methods using lime or limestone as sorbents.

R&D efforts in FGD have been directed, for the most part, toward either decreasing the quantities of the reaction coproducts or increasing their economic value to upgrade them to resources from waste products.

Outlook

The increase in the production of fly ash and bottom ash will be proportional to the increase in coal use for electric power production, which may be limited to 5% to 7% per year. Increase in the FGD product, however, is another matter. As mentioned above, phase one of the CAAA'90 affected only 10% of the coal-burning electric utilities. With phase two, the remaining 90% of the utilities will be subject to the emissions restrictions set by the law. The majority of the utilities affected by phase one met the restrictions with short-term remedies, such as fuel switching, emission allowance purchases, and reduction of power production where feasible. Such temporary measures, however, shall not be available to all. Projections indicate that 20 million tons of annual FGD production may increase by an order of magnitude to almost 200 million tons, far exceeding the total quantities of the other three components of the CCP's. A number of wet-lime-based FGD units that will triple the amount of FGD material produced are already under construction. Planned capacity may multiply the current output by six fold. This will present a challenge to electric utilities and such industries, as construction, agriculture, and certain manufacturing sectors to find increased uses for these materials.

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Radian Corporation, 1983, The evaluation and status of the flue gas desulfurization systems, Research Project 982-28, Final Report, 8501 Mo-Pac Boulevard, Austin, TX, 631 p.

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Other

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McIlvaine Company, FGD and NO_x Manual, v. 2.

[1]Prior to January 1996, published by the U.S. Bureau of Mines.

TABLE 1
HISTORICAL COAL COMBUSTION PRODUCT (CCP) PRODUCTION AND USE

(Thousand metric tons)

	1993	1994	1995	1996	1997
Fly ash:					
Production	43,400	49,800	49,200	53,900	54,700
Use	9,540	11,700	12,300	14,700	17,500
Percent use	22.00	23.60	25.00	27.50	32.10
Bottom ash:					
Production	12,900	13,500	13,800	14,600	15,400
Use	3,840	4,610	4,600	4,430	4,600
Percent use	29.80	34.30	33.30	30.40	30.20
Boiler slag:					
Production	5,660	3,440	2,550	2,360	2,490
Use	3,110	2,830	2,440	2,170	2,340
Percent use	55.10	82.30	95.70	92.30	94.10
FGD 1/ material:					
Production	18,500	14,100	18,100	21,700	22,800
Use	1,050	850	1,340	1,500	1,980
Percent use	5.70	6.05	7.41	6.96	8.67
Total CCP's:					
Production	80,400	80,800	83,700	92,400	95,400
Use	17,500	20,000	20,700	22,800	26,500
Percent use	21.80	24.80	24.90	24.90	27.80

1/ FGD, flue gas desulfurization.

Source: American Coal Ash Association.

TABLE 2

TOTAL COAL COMBUSTION PRODUCT (CCP) PRODUCTION AND USE, 1/ 1997

(Thousand metric tons)

	Fly ash	Bottom ash	Boiler slag	FGD 2/ material	Total all CCP's
Production:					
Disposed	35,600	9,880	390	15,900	61,700
Produced	54,700	15,400	2,490	22,800	95,400
Removed from disposal	1,200	440	270	70	1,970
Stored on-site	3,170	1,430	70	5,030	9,690
Use:					
Agriculture	30	10	--	50	90
Blasting grit/roofing granules	--	150	2,080	--	2,200
Cement - concrete - grout	8,550	550	10	180	9,300
Flowable fill	350	10	--	--	360
Mineral filler	260	120	100	--	480
Mining applications	1,280	150	--	100	1,530
Roadbase - subbase	1,290	1,170	--	20	2,480
Snow and ice control	--	660	50	--	710
Structural fills	2,610	1,260	80	--	3,950
Wallboard	--	--	--	1,460	1,460
Waste stabilization - solidification	2,830	190	--	10	3,030
Other	330	380	30	170	900
Total use	17,500	4,630	2,340	1,980	26,500
Individual use percentage	32.10	30.20	94.10	8.70	NA
Cumulative use percentage	32.10	31.60	33.80	27.80	27.80

NA Not available.

1/ Total CCP's include Categories I and II; Dry and Ponded respectively.

2/ FGD, flue gas desulfurization.

Source: American Coal Ash Association.

TABLE 3

DRY COAL COMBUSTION PRODUCT (CCP) PRODUCTION AND USE, 1997

(Thousand metric tons)

	Fly ash	Bottom ash	Boiler slag	FGD 1/ material	Total all CCP's
Production:					
Disposed	22,600	6,120	140	9,860	38,800
Produced	37,600	9,300	820	12,300	60,000
Removed from disposal	630	200	30	--	680
Stored on-site	1,430	500	10	990	2,930
Use:					
Agriculture	30	10	--	50	90
Blasting grit/roofing granules	--	80	640	--	720
Cement - concrete - grout	8,010	410	--	160	8,590
Flowable fill	300	10	--	--	310
Mineral filler	260	120	10	--	390
Mining applications	780	110	--	--	890
Roadbase - subbase	1,210	900	10	--	2,110
Snow and ice control	--	400	10	--	410
Structural fills	1,340	350	40	--	1,730
Wallboard	--	--	--	1,220	1,220
Waste stabilization - solidification	1,900	160	--	10	2,070
Other	230	310	--	40	580
Total use	14,100	2,880	700	1,490	19,100
Individual use percentage	37.40	31.00	84.90	12.00	NA
Cumulative use percentage	37.40	36.10	37.00	31.90	31.90

NA Not available.

1/ FGD, flue gas desulfurization.

Source: American Coal Ash Association.

TABLE 4
PONDED COAL COMBUSTION PRODUCT (CCP) PRODUCTION AND USE, 1997

(Thousand metric tons)

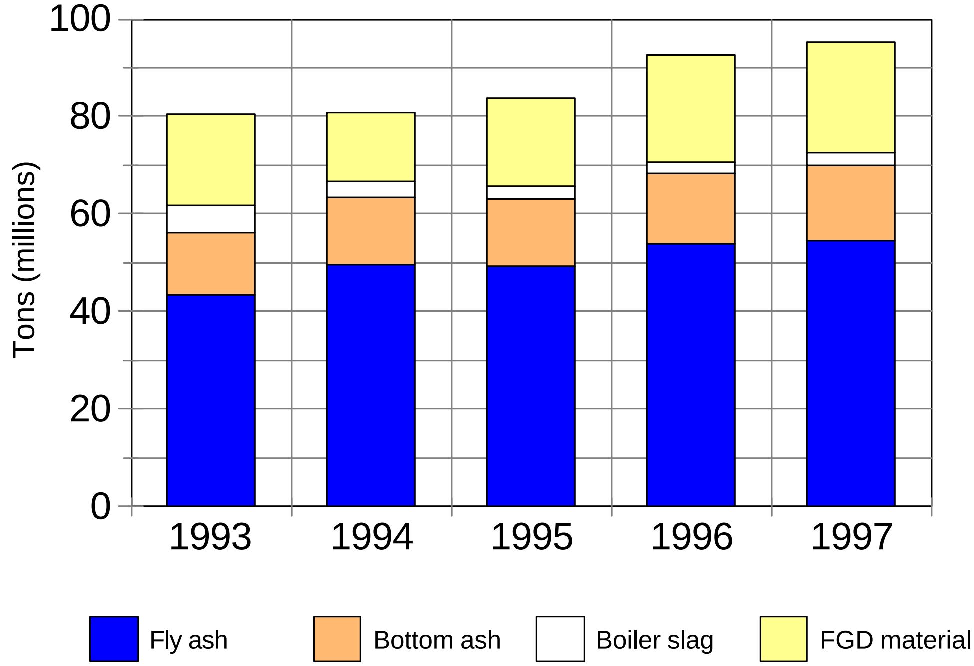
	Fly ash	Bottom ash	Boiler slag	FGD 1/ material	Total all CCP's
Production:					
Disposed	12,900	3,760	240	6,020	23,000
Produced	17,100	6,050	1,670	10,500	35,400
Removed from disposal	570	240	240	70	1,120
Stored on-site	1,740	930	50	4,140	6,760
Use:					
Agriculture	--	--	--	--	--
Blasting grit/roofing granules	--	60	14,440	--	1,500
Cement - concrete - grout	540	130	10	20	710
Flowable fill	50	--	--	--	50
Mineral filler	--	--	90	--	90
Mining applications	500	30	--	90	630
Roadbase - subbase	70	270	--	20	360
Snow and ice control	--	250	40	--	290
Structural fills	1,270	900	40	--	2,220
Wallboard	--	--	--	240	240
Waste stabilization - solidification	930	20	--	--	950
Other	100	60	30	130	320
Total use	3,470	1,750	1,640	500	7,360
Individual use percentage	20.30	28.90	98.60	4.70	NA
Cumulative use percentage	20.30	22.50	27.50	20.80	20.80

NA Not available.

1/ FGD, flue gas desulfurization.

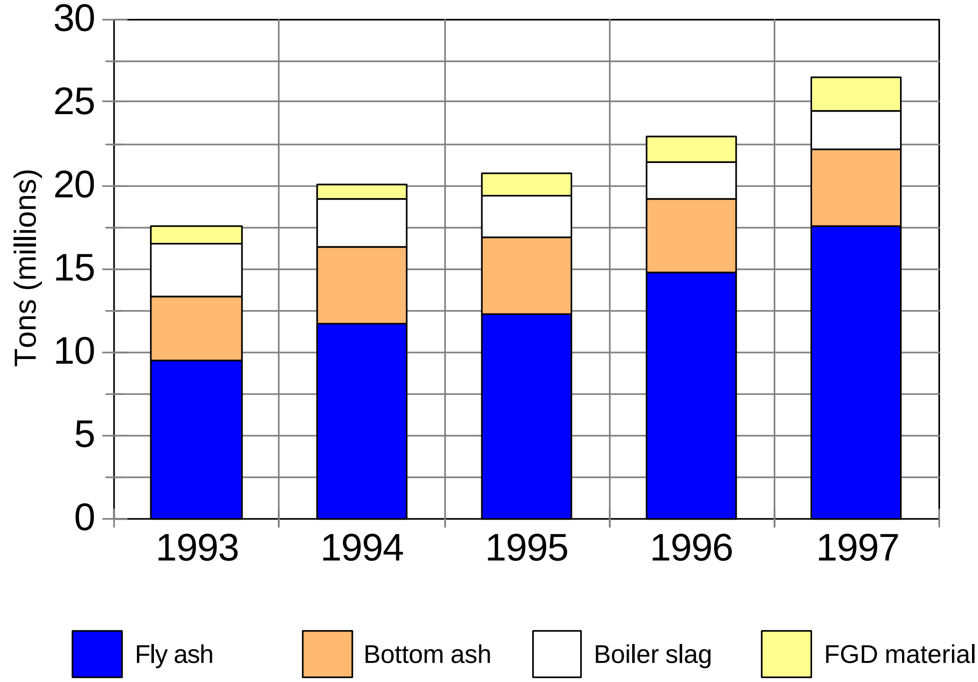
Source: American Coal Ash Association.

FIGURE 1
HISTORICAL CCP PRODUCTION DATA, 1993-1997



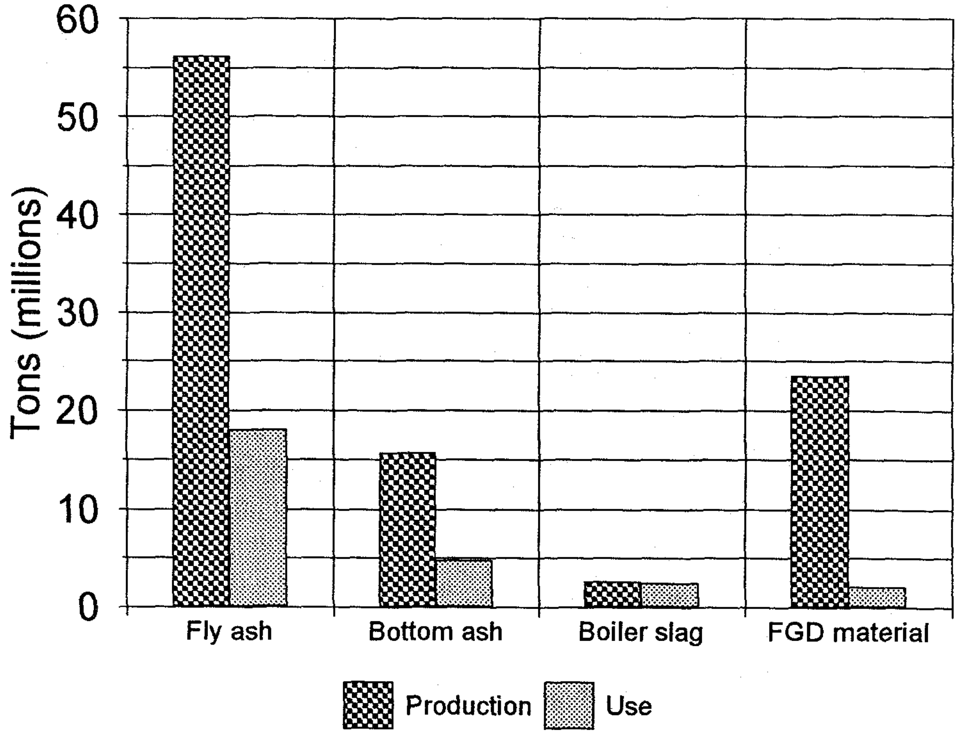
Source: American Coal Ash Association

FIGURE 2
HISTORICAL CCP USE DATA, 1993-1997



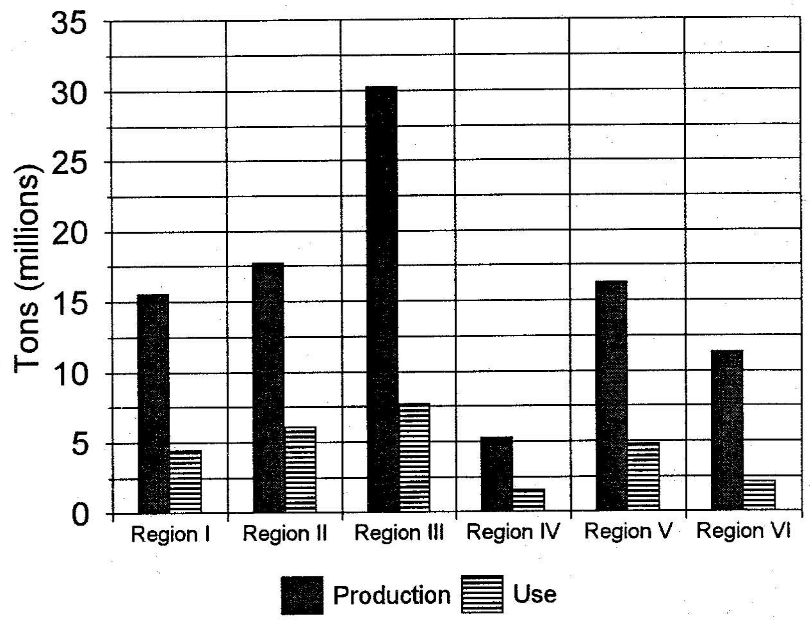
Source: American Coal Ash Association

FIGURE 3
CCP PRODUCTION AND USE FOR THE UNITED STATES, 1997



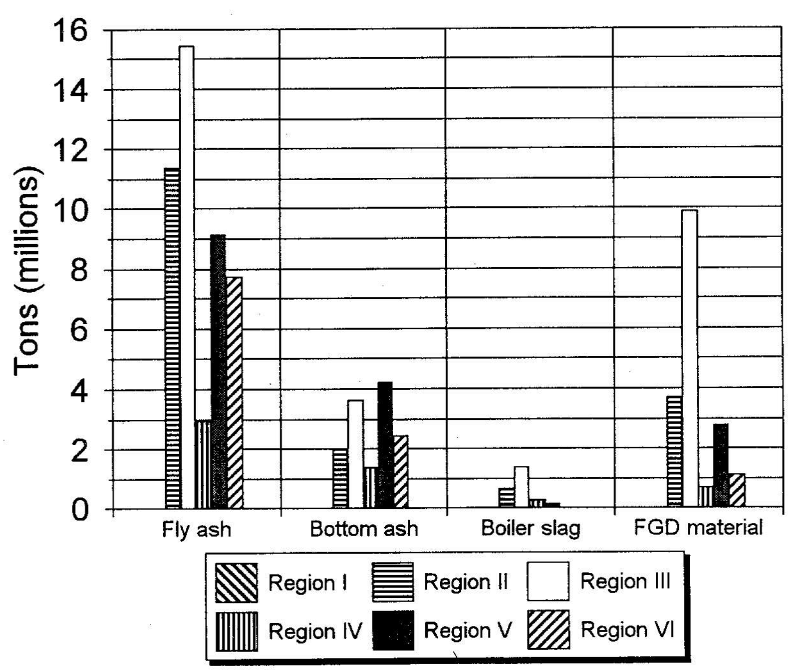
Source: American Coal Ash Association

FIGURE 4
CCP PRODUCTION AND USE BY REGION, 1997



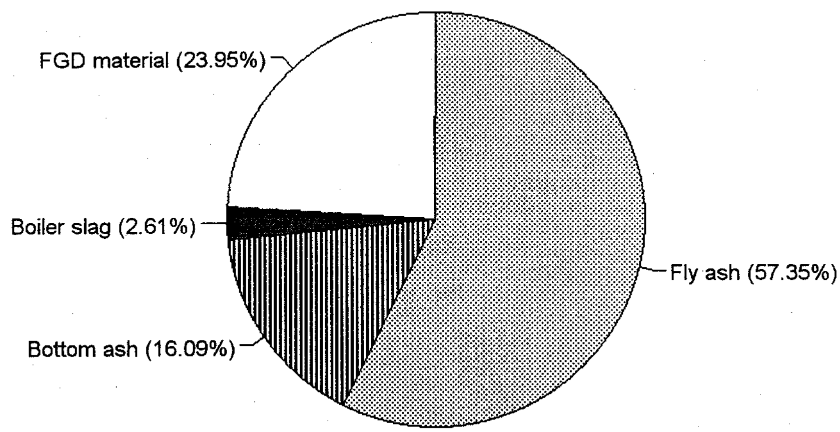
Source: American Coal Ash Association

FIGURE 5
CCP PRODUCTION BY TYPE AND REGION, 1997



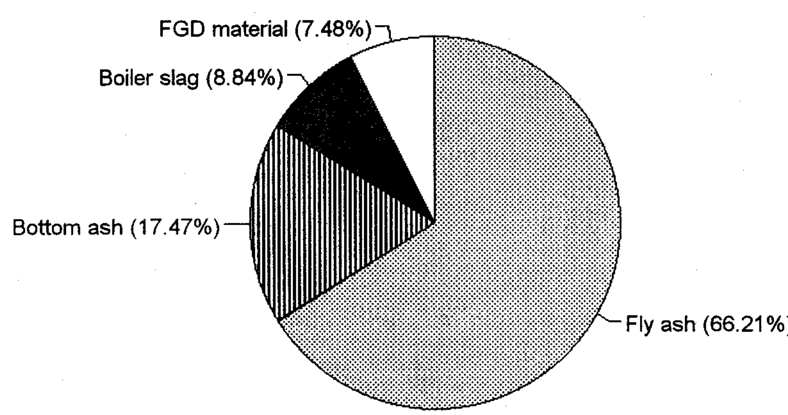
Source: American Coal Ash Association

FIGURE 6
CCP PRODUCTION BY TYPE, 1997



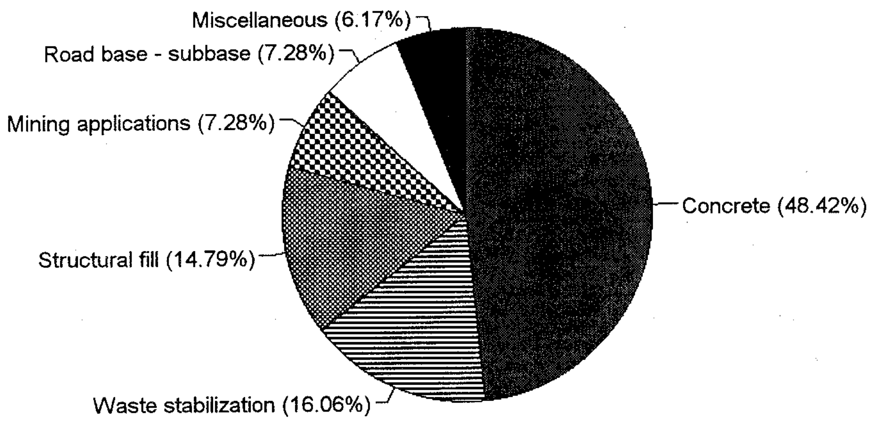
Source: American Coal Ash Association

FIGURE 7
CCP USE BY TYPE, 1997



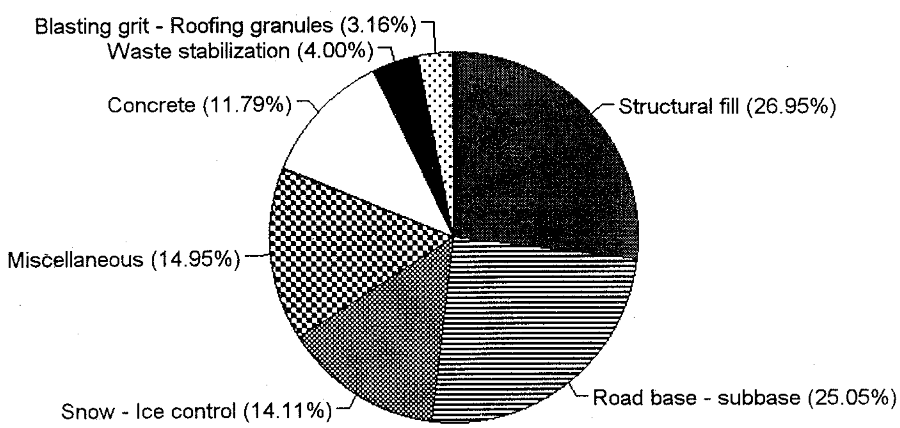
Source: American Coal Ash Association

FIGURE 8
LEADING COAL FLY ASH USES, 1997



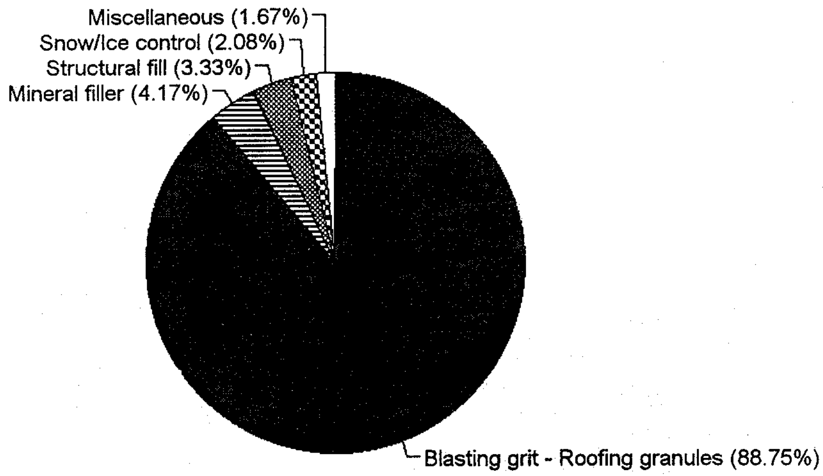
Source: American Coal Ash Association

FIGURE 9
LEADING BOTTOM ASH USES , 1997



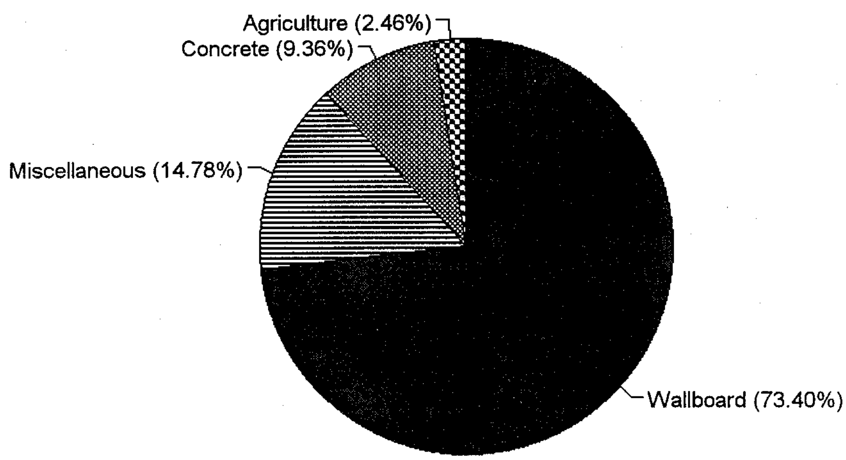
Source: American Coal Ash Association

FIGURE 10
LEADING BOILER SLAG USES, 1997



Source: American Coal Ash Association

FIGURE 11
LEADING FGD MATERIAL USES, 1997



Source: American Coal Ash Association

FIGURE 12
REGIONS OF THE UNITED STATES